Rock Island Arsenal Laboratory

TECHNICAL REPORT

INVESTIGATION OF VOLATILE CORROSION INHIBITOR ADDITIVES FOR STANDARD OPERATING OILS TO IMPROVE THEIR PRESERVATIVE CHARACTERISTICS

By

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21 December 1964

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Rock Island Arsenal
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ABSTRACT

Nine volatile corrosion inhibitor (VCI) concentrates were evaluated in eight selected base oils to determine the feasibility of utilizing a VCI concentrate to improve the preservative properties of operating lubricants.

The work reasonably demonstrated the feasibility of using carefully selected concentrates to improve the preservative properties of an operating lubricant. However, unpredictable compatibility problems may prevent a practical application of this process.

Three promising concentrates were found that would provide vapor phase protection comparable to that of Specification MIL-L-46002 VCI oil, and exhibited only slight sedimentation in compatibility tests with operating lubricants. Of the three, only one had the supply and logistics properties deemed to be most desirable.

It was revealed that concentrates in liquid form were best suited because solubility problems were encountered with the powdered form of concentrate.

The type of diluent which is part of the concentrate can also produce detrimental effects on a product when it is added to an operating oil as evidenced by drastic changes in viscosity, pour point and flash point.

RECOMMENDATIONS

It is recommended that a pilot test be conducted whenever a VCI oil concentrate is to be blended with a finished product to insure that the specific combination is compatible and will not adversely affect the equipment involved.

It is recommended that consideration be given to the further investigation of this basic concept by the following:

1. Determine the effects of oxidized oils, or oils which have been in storage for a considerable period of time, on the protection, compatibility, and physical characteristics of the oil-concentrate mixtures.

2. Determine the causative effects of the incompatibilities which exists between MIL-L-2104, Grade 30 oil and the VCI concentrate during long term storage.

3. Determine if an inhibitor in a solvent-base concentrate can be effectively utilized in an oil base concentrate.

4. Initiate engine storage tests on the effective VCI concentrates to ascertain their value in actual service.

5. Determine the long term storage characteristics of unused, undiluted VCI concentrates.

6. Determine the most desirable dilution ratio to provide an optimum protection level for use with engine, hydraulic, or general purpose lubricants

FOREWORD

This report was prepared by Springfield Armory under contract to Rock Island Arsenal.

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INVESTIGATION OF VOLATILE CORROSION INHIBITOR ADDITIVES FOR STANDARD OPERATING OILS TO IMPROVE THEIR PRESERVATIVE CHARACTERISTICS

OBJECT

To determine the practicality and feasibility of upgrading the protection characteristics of standard operating lubricants and hydraulic oils by the addition of a volatile corrosion inhibitor (VCI) concentrate.

INTRODUCTION

Military equipment and machinery is normally subjected to varying periods of intermittent operation during its life. The satisfactory storage and protection afforded the closed lubricant and hydraulic systems of such equipment during non-use periods is of prime importance because inadequate protection against corrosion can result in costly repairs, and undesirable downtime. Moreover, the lack of protection may result in equipment failures under extremely critical service conditions.

Basically, in a closed lubrication system such as engine crankcases, transmissions, or hydraulic systems, the oil will, in non-use periods, tend to drain off the upper and vertical surfaces to the normal oil level, leaving areas with inadequate protection. Conventional contact inhibitors, such as sulfonates, amines, or fatty acid derivatives, protect only when in direct contact with a surface. The drained areas are thus subject to corrosion damage, and in systems with delicate operational mechanisms or critical surfaces even very slight corrosion can result in decreased efficiency, malfunctions, or even non operation. The corrosion protection of such areas or systems would be greatly improved if the drainage characteristics of the usual preservative oils could be modified or minimized. This, however, is not possible to any acceptable degree at the present time. A similar effect can, however, be achieved if the preservative oil contains, in addition to the contact inhibitors, a volatile inhibitor which will produce rust inhibition within the closed system without direct contact of oil and surface. Such a condition has been produced in the past with certain volatile corrosion inhibitor oils conforming to Specs MIL-L-46002(Ord) and MIL-I-23310(Wep). These oils are, however, specifically preservative oils and not operational oils, and at best are not intended for

continuous nonpreservative operation. Moreover, another drawback is the general requirement that the part or vehicle, when ready for a non-use or storage period, must be cleaned and preserved. Apart from the cleaning which is a most important factor, the preservation process requires the use of special preservative oils designed for the purpose, - weapons, hydraulic, automotive, etc., and these must be in stock or easily available when needed. Then, upon depreservation, it is further advisable to remove the preservative and install the operational oil. Stocks of both preservative and operational oils are required, and in general the preservative oils will not be the same for hydraulic as for weapons or automotive uses.

If a VCI additive were available which was compatible with the operational oil the system, after cleaning, could be charged with operational oil to which the VCI concentrate was added, and placed in storage in normal fashion. Upon depreservation, the part could be put into use at once without any need to change the oil. The VCI material would volatilize with the heat of use, and the residue would be operational oil.

The use of the VCI concentrate in this manner represents significant savings in storage, labor, and inventory problems, besides reducing the possibilities of error thru choice of the wrong preservative. These savings represent a considerable advantage, and where short use periods alternate with long idle periods, the addition of a "dash" of VCI concentrate could in the long run prevent considerable damage from corrosion.

At the present time, a number of VCI concentrates in powder, oil, or solvent solution form are available, but no concerted investigations of these materials have been undertaken. In order to provide necessary data concerning the use of VCI concentrates, it was proposed to investigate the practicality and feasibility of adding a VCI concentrate to standard operating lubricant and hydraulic oils to enhance their protective characteristics. The results obtained would determine the feasibility of continuing this line of investigation.

PROCEDURE AND RESULTS

The following finished oil products were selected to be blended with various VCI concentrates.

1. Heavy Duty Internal Combustion Engine Lubricating Oil, MIL-L-2104, Grade 10 and Grade 30

2. General Purpose Lubricating Oil, MIL-L-15016 #2110 (SAE10), and #3065 (SAE30)

3. Petroleum Base Hydraulic Fluid for Machine Tools. MIL-H-46001 light, MIL-H-46001 medium.

4. Petroleum Base Hydraulic Fluid, Aircraft, Missile and Ordnance MIL-H-5606

5. Petroleum Base Hydraulic Fluid-Preservative MIL-H-6083

The concentrates which were tested, and the suggested dilution ratios, are as follows

Code A	liquid	1-3
B	liquid	1-10
C	liquid	1-3
D	solvent solution	1-5
E	Powder	7-1/2% by weight
F	Powder	15% by weight
G	Powder	7-1/2% by weight
H	thixotropic gel	7-1/2% by weight
I	Powder	15% by weight

The volatile corrosion inhibitor concentrates were added to each of the base oils in accordance with the suppliers suggested use ratios. Both the liquid and powder concentrates were blended with the oils on a weight basis In order to facilitate the solution of the powders in the base oils the crystals were finely ground before addition to the respective oils.

A. EXHAUSTION AND VAPOR PHASE PROTECTION TESTS

After the addition of the concentrates to the oils, the mixtures were exhausted as specified in par. 4.8.3 of Specification MIL-L-46002 The exhaustion procedure utilized the evaporation test cell specified in Method 351 of Federal Standard No. 791 The protective properties of the exhausted materials were then established utilizing the vapor phase protection test of Spec. MIL-L-46002 A slight modification was made in the equipment used for this latter test The steel panels are normally positioned in the jar by means of a monel wire support, but due to the flexibility of the support and the size limitations of the jar the panels would be partially immersed in the test oil. The area to be protected was thus not constant To eliminate this actual contact between oil and panel, a new fixture was devised wherein a curved section of monel wire was permanently affixed to the test jar lid with an epoxy

resin cement. This modification provided a uniform vapor phase environment for all panels, since the entire panel was now suspended above the test oil in the jar without any contact.

These tests were considered to be the most important of all, and were based on a requirement to achieve results equivalent to a VCI-oil such as MIL-L-46002. Moreover, these tests would provide guidance for continuation of the project. Results were tabulated in Table I.

Referring to Table I, it is noted that Code A concentrate provided satisfactory protection with all oils tested. The required dilution of 1-3 was not as desirable as a lower dilution, and the manufacturer supplied another concentrate, Code B, intended for a 1-10 dilution ratio. At this ratio 5 of the 8 oil bases failed. Of these 5, four were satisfactory at a 1-9 ratio, and in the last case, MIL-L-15016 (3065) the lowest satisfactory ratio was 1-7.

The Code C concentrate was tested at a 1-3 ratio with MIL-L-2104 (Grade 10 and Grade 30) and found to be unsatisfactory. Further testing was discontinued.

The Code D concentrate was tested at a 1-5 ratio without satisfactory results, using SAE 10 oils of MIL-L-2104 and MIL-L-15016. When a 1-3 ratio was used, it was satisfactory with all the oils except MIL-H-6083. No test was run with 6083 due to incompatibility as reported later.

The tests on powder concentrates (Codes E, F, G, H and I) showed that Code G was unsatisfactory at concentrations up to 10% while Code E was satisfactory at 7-1/2% in MIL-L-2104 oils. Code H failed at 7-1/2% and Code F which required a 15% concentration, also failed. The Code I, at 15% concentration, passed the tests with all oils except MIL-H-6083 which was not tested due to incompatibility.

These results indicated that Codes A, B, D, E and I could be added to a variety of oils and provide protection. Other factors, however, needed to be considered relative to the operational and related properties of the original oils.

B. SHORT AND LONG TERM COMPATIBILITY TESTS

Short and long term compatibility tests with the various base oils were run on some of the concentrates. Storage of the treated oils for short and long terms at

TABLE I

VAPOR PHASE PROTECTION TESTS ON BLENDS OF OPERATING OILS AND VARIOUS CONCENTRATES (AFTER EXHAUSTION)

Concentrate / Operating Oil	Code A	Code B				Code C	Code D		Code E	Code F	Code G	Code H	Code I
									Concentrations				
	1:3 Ratio	1:10 Rati	1:9 Ratio	1:8 Ratio	1:7 Ratio	1:3 Ratio	1:5 Ratio	1:3 Ratio	7-1/2%	15%	10%	7-1/2%	15%
MIL-L-2104 Grade 10	Passed	Passed	-	-	-	Failed	Failed	Passed	Passed	Failed	Failed	Failed	Passed
MIL-L-2104 Grade 30	Passed	Passed	-	-	-	Failed	-	Passed	Passed	Failed	Failed	Failed	Passed
MIL-L-15016 SAE 10 (2110)	Passed	Failed	Passed	-	-	-	Failed	Passed	-	-	-	-	Passed
MIL-L-15016 SAE 30 (3065)	Passed	Failed	Failed	Failed	Passed	-	-	Passed	-	-	-	-	Passed
MIL-L-46001 Light	Passed	Failed	Passed	-	-	-	-	Passed	-	-	-	-	Passed
MIL-L-46001 Medium	Passed	Failed	Passed	-	-	-	-	Passed	-	-	-	-	Passed
MIL-H-5606	Passed	Failed	Passed	-	-	-	-	Passed	-	-	-	-	Passed
MIL-H-6083	Passed	Passed	-	-	-	-	-	Not Tested	-	-	-	-	Not Tested

room temperature, approximately 80°F., comprised a 5 day short term test with daily inspections and a 12 month long term test with daily inspections for the first 5 days, followed by monthly checks until completion of the tests. Table II indicates compatibility by observing solubility after the short term test.

Of the liquid concentrates, Codes A and B were compatible with all the base oils, and Codes C and D with all except MIL-H-6083.

In order for a concentrate to be useful it must mix easily, rapidly, and completely with the base oil. This would, therefore, require that a powder concentrate be almost instantly soluble. The powder concentrates Codes E, F, G, and I were difficultly soluble in every case.

The powders were easier to blend into the lighter oils than into the heavier bodied oils. Agitation and heat aided in dissolving the powders, but in field use this may not always be possible. The concentrate would not dissolve completely to provide the desired protection. The recommended 7-1/2% portions of Codes E and G were most difficult to dissolve in the base oils. Even at 3-1/2% the blended solution was difficult to obtain without heat and agitation. The use of heat for this purpose has two major disadvantages (1) it may not be available, and (2) it may prematurely dissipate the volatile inhibitor material. These materials (Codes E and G) were compatible only with MIL-H-5606 and formed a gel with MIL-H-6083.

A modification of the short term storage test was conducted on concentrates marked Code A, Code B, and Code C. Three samples of each concentrate were stored for two weeks at 160°F., 40°F., and -65°F. At the end of the storage period the samples were examined visually for separation and then added in the proper amount to MIL-L-2104 engine oil. The base inhibitor mixes which had been stored at 160°F. and 40°F. were mixed with Grade 30 oil and were then evaluated for vapor phase inhibition. The inhibitors stored at -65°F. were mixed with Grade 10 oil and tested as above. These variations were made to observe the rapidity and completeness of mixing, especially with the low temperature concentrate, since some of the desirable attributes of a concentrate are ease and rapidity of mixing.

The results obtained indicated no adverse effects on corrosion protection afforded by Code A and Code B concentrates when stored for 2 weeks at temperatures of 160°F., 40°F. and -65°F. Code C concentrate provided satisfactory corrosion protection after storage at 40°F.

TABLE II

SHORT TERM COMPATIBILITY TESTS ON TREATED OILS

Oils	Code A VCI Conc. 1:3 Ratio	Code B VCI Conc. 1:10 Ratio	Code C 1:3 Ratio	Code D 1:3 Ratio	Code E 3-1/2%	Code G 3-1/2%
MIL-L-2104 Grade 10	C	C	C	C	PC	PC
MIL-L-2104 Grade 30	C	C	C	C	PC	PC
MIL-L-15016 SAE 10(2110)	C	C	C	C	PC	PC
MIL-L-15016 SAE 30(3065)	C	C	C	C	PC	PC
MIL-L-46001 Light	C	C	C	C	PC	PC
MIL-L-46001 Medium	C	C	-	C	--	--
MIL-H-5606	C	C	C	C	C	C
MIL-H-6083	C	C	NC	NC	NC	NC

C - Compatible
NC - Non Compatible
PC - Partially Compatible

but was adversely affected by the temperature extremes of -65°F. and 160°F. The concentrate did not provide corrosion protection as required in the vapor phase protection test of MIL-L-46002.

A cycling test with Code A and Code B concentrates was planned with samples stored for one week at 160°F., room temperature, 40°F., and -65°F., consecutively. The vapor phase protection test per paragraph 4.8.2 of Spec. MIL-L-46002 was conducted with MIL-L-2104 engine oil at the end of each week's test. The original samples were 100 ml of concentrate in a sealed container. The test progressed thru the temperature ranges until the -65°F. temperature was reached.

It was shown that Code A and Code B concentrates provided the desired corrosion protection thru the first three temperature test points. The effects of the concentrate stored at -65°F. were not determined due to the mechanical failure of the low temperature environmental test chamber after one day's operation.

The long term capatibility tests were originally intended for a one year term, however, only six months testing could be completed on the most promising inhibitors, Code A and Code B. These results are indicated in Table III.

It is noted that after 6 months storage, the inhibitors were found to be compatible with only the MIL-H-5606 fluid. A light flocculent type of sedimentation was evident with five of the base oils; however, this was easily redispersed. While it might well form in situ, it is believed that no significant effects would ensue since, in service, the equipment upon being activated would redisperse the sediment without adverse effect.

The MIL-L-2104, Grade 30 oil formed a heavy precipitate. Although the precipitate would be redispersed in actual use, there is a question concerning its suitability, since the volume of the precipitate denotes some interaction with the other additives. The acceptability of the sedimentation in any case would depend on the continued protective properties of the mixture, as noted in Table IV. The MIL-H-6083 was unsatisfactory as a gelatinous precipitate was formed.

It was intended to establish the protective properties of the stored concentrate-oil mixtures utilizing the vapor phase protection test. Time permitted only the evaluation of the Code A concentrate. These results are indicated in Table IV.

TABLE III

SIX MONTH STORAGE COMPATIBILITY TESTS ON TREATED OILS

Oil	Code A 1:3 Ratio	Code B 1:10 Ratio
MIL-L-2104 Grade 10	Light ppt	Light ppt
MIL-L-2104 Grade 30	Heavy ppt	Heavy ppt
MIL-L-15016 SAE 10 (2110)	Light ppt	Very Light ppt
MIL-L-15016 SAE 30 (3065)	Light ppt	Very Light ppt
MIL-L-46001 Light	Very Light ppt	Very Light ppt
MIL-L-46001 Medium	Light ppt	Very Light ppt
MIL-H-5606	Compatible	Compatible
MIL-H-6083	Gelatinous ppt	Gelatinous ppt

TABLE IV

RESULTS OF VAPOR PHASE PROTECTION TEST ON OILS TREATED WITH 1:3 RATIO CODE A STORED FOR SIX MONTHS

MIL-L-2104 Grade 10	Passed
MIL-L-2104 Grade 30	Failed
MIL-L-15016 SAE 10 (2110)	Passed
MIL-L-15016 SAE 30 (3065)	Passed
MIL-L-46001 Light	Passed
MIL-L-46001 Medium	Passed
MIL-H-5606	Passed
MIL-H-6083	Passed

It is noted that the only failure was obtained with the MIL-L-2104, Grade 30 oil, where a large amount of sedimentation had occurred. This was very likely caused by an interaction of inhibitors, however, further study is required before any definite conclusions can be drawn.

Incomplete tests on the Code B concentrate showed that similar results would probably be obtained at the 1:10 or 1:9 ratios for the respective oils as noted in Table III

C. VISCOSITY TESTS

Since the addition of a VCI concentrate to a base oil may affect the viscosity characteristics, Codes A, B and D concentrates, which had passed the exhaustion and vapor phase tests, were evaluated for viscosity effects according to Method 305 of Federal Standard No. 791.

As indicated in Table V, the addition of Code A and B concentrates caused a significant viscosity change only in the case of the MIL-L-15016 (#3065) base oil. For the other base oils, any changes evident did not cause the viscosity to deviate significantly from the specification requirements.

The Code D concentrate, being a solvent solution, caused noticeable viscosity changes. The presence of the solvent is a hindrance in many ways and undoubtedly will require some remedial action if the material is to be given any further consideration.

D. FLASH POINT TESTS

Similarly, the flash point was determined for Code A, B and D concentrates in various base oils in accordance with Method 1103 of Federal Standard 791. These results are indicated in Table VI.

It is noted that, with two exceptions, there was a significant lowering of the flash point by the addition of a concentrate. This was especially true with Code D concentrate, a xylene solution. For the Code A and B concentrates, the effects seemed to be more a function of the inhibitor rather than the carrier oil, which was probably an SAE 10 oil.

E. POUR POINT TESTS

Similarly, the pour point was determined for Code A, B and D concentrates in various base oils in accordance with Method 201 of Federal Standard No. 791.

TABLE V

VISCOSITY TESTS ON TREATED OILS AS COMPARED TO VISCOSITY OF BASE OIL

Oil	*Viscosity Centi-Stokes	*Temp. °F	Code A VCI Conc. 1:3 Ratio	1:10 Ratio	Code B VCI Conc. 1:9 Ratio	1:7 Ratio	Code D VCI Conc. 1:3 Ratio
MIL-L-2104 Grade 10	5.44-7.29	210	6.1	6.4			4.5
MIL-L-2104 Grade 30	9.65-12.98	210	9.5	12.9			6.5
MIL-L-15016 SAE 10 (2110)	8.15-25.20	130	21.0		18.8		14.5
MIL-L-15016 SAE 30 (3065)	60-75	130	34.1			38.3	19.7
MIL-L-46001 Light	30-37	100	31.6		29.2		20.5
MIL-L-46001 Medium	42-52	100	42.3		38.4		22.6
MIL-H-5606	10.0 Min	130	12.2		10.5		9.1
MIL-H-6083	10.0 Min	130	11.9	11.2			Not Tested

*Viscosity and temperature values obtained from specification requirements of base oils

TABLE VI

FLASH POINTS OF TREATED OILS VS FLASH POINTS OF BASE OILS

Oil	Flash Point* °F Min	Code A VCI Conc. 1:3 Ratio Flash Point °F	Code A VCI Conc. 1:3 Ratio % Change	Code B 1:10 Ratio Flash Point °F	Code B 1:10 Ratio % Change	VCI Concentrate 1:9 Ratio Flash Point °F	VCI Concentrate 1:9 Ratio % Change	VCI Concentrate 1:7 Ratio Flash Point °F	VCI Concentrate 1:7 Ratio % Change	Code D 1:3 Ratio Flash Point °F	Code D 1:3 Ratio % Change
MIL-L-2104 Grade 10	360	320	-11.1	300	-16.7					200	-44.5
MIL-L-2104 Grade 30	390	345	-11.5	330	-15.4					275	-42.3
MIL-L-15016 SAE 10 (2110)	325	315	- 3.1			280	-16.1			190	-41.5
MIL-L-15016 SAE 30 (3065)	410	315	-23.2					290	-41.4	190	-53.7
MIL-L-46001 Light	325	320	- 1.5			250	-30.0			175	-46.2
MIL-L-46001 Medium	325	340	+ 4.6			255	-28.0			185	-43.2
MIL-H-5606	200	200				175	-14.3			160	-20.0
MIL-H-6083	200	225	+12.5	160	-20.0					Not Tested	

*Flash point values obtained from specification requirements of base oils.

It is noted in Table VII that with two exceptions, the MIL-L-2104, Grade 10 oil and the MIL-L-15016, SAE 30 oil, all of the pour point values were lowered by the addition of a concentrate. The most significant changes were made by the Code D concentrate and this was attributed to the influence of the xylene solvent. Lowering of pour points may at times be considered advantageous, especially with the lower viscosity oil base materials evaluated.

F. SURVEY OF PROTECTION TESTS ON MIL-L-2104 QUALIFIED PRODUCTS

Since the original MIL-L-2104 oils, obtained from local stocks, probably represented only one supplier, it was decided to obtain samples directly from three additional qualified suppliers. Vapor phase protection tests were made with the different oil samples utilizing Code A, B and D concentrates at the previously determined effective concentration.

Referring to Table VIII, it is noted that all mixtures satisfactorily passed the exhaustion and vapor phase protection tests.

TABLE VIII

EXHAUSTION PLUS VAPOR PHASE PROTECTION ON MIL-L-2104 OILS

	1-3 Code A	1-10 Code B	1-3 Code D
Sunoco Sunvis 610	OK	OK	OK
Sunoco Sunvis 630	OK	OK	OK
Atlantic Ultramo SAE 10	OK	OK	OK
Atlantic Ultramo SAE 30	OK	OK	OK
Texaco HD 10 W	OK	OK	OK
Texaco HD 30 W	OK	OK	OK

DISCUSSION

The primary criteria as to the merits of various volatile corrosion inhibitor concentrates was based on the results obtained from exhaustion and vapor phase protection tests. Periodic testing of uninhibited oils provided checks on the technique used during this

TABLE VII

POUR POINTS OF TREATED OILS VS POUR POINTS OF BASE OILS

Oil	Pour Point* °F	Code A VCI Conc. 1:3 Ratio Pour Point °F	Code A VCI Conc. 1:3 Ratio Change °F	Code B VCI Concentrate 1:10 Ratio Pour Point °F	1:10 Ratio Change °F	1:9 Ratio Pour Point °F	1:9 Ratio Change °F	1:7 Ratio Pour Point °F	1:7 Ratio Change °F	Code D 1:3 Ratio Pour Point °F	Code D 1:3 Ratio Change °F
MIL-L-2104 Grade 10	-20	-5	+15	-10	+10					-20	0
MIL-L-2104 Grade 30	0	-5	-5	-5	-5					0	0
MIL-L-15016 SAE 10 (2110)	0	-10	-10			0	0			-20	-20
MIL-L-15016 SAE 30 (3065)	+5	-15	-20					+10	+5	-10	-15
MIL-L-46001 Light	+10	-10	-20			+5	-5			0	-10
MIL-L-46001 Medium	+10	-15	-25			0	-10			-20	-30
MIL-H-5606	-75	-80	-5			-90	-15			-90	-15
MIL-H-6083	75	-80	-5	-85	-10					Not Tested	Not Tested

*Pour point values obtained from specification requirements on base oils.

evaluation.

The treated oils were exhausted before being evaluated in the vapor phase protection test due to the possibility that treated oils in actual use may dissipate some of the volatile corrosion inhibitor before the desired protection is needed.

The satisfactory vapor phase protection results obtained on the various mixtures utilizing oil concentrates indicated the effectiveness of converting operating oils to preservative oils The powder concentrates, however, were unsuitable for this application due to the high concentration of VCI that must be employed. From the overall results obtained, the powder concentrates warrent no further investigation.

The storage stability test data indicated certain areas of incompatibility. One of these was the MIL-L-2104, Grade 30 and Code A mixture Since this lubricant is so widely used, it will be necessary to determine which of the additives present in the base oil is the cause of the incompatibility.

Due to the favorable results obtained in the modified short term storage test, it was decided to extend this type of test from two weeks to six months. Tests are currently in process utilizing the extended storage period.

The cycling test was devised to evaluate radical temperature changes that may occur in environmental storage. Frequently material is stored at high, alternately average, or low temperatures for varying time intervals. A cycling test simulates this type of storage condition As previously indicated, the low temperature phase of the test cycle was not completed due to mechanical failure of the low temperature test chamber. Satisfactory results were obtained, however, for the other test temperatures.

In determining the feasibility of using a volatile corrosion inhibitor, the resulting viscosity of the blended mixture is important due to the fact that the addition of the concentrate may affect the allowable viscosity limits of the base material. An adverse viscosity change at -65°F. might make the mixture unuseable. It is, therefore, evident that a VCI additive should only be considered for those lubricants which in themselves are better than marginal at low temperatures.

Similar care should also be exercised when considering flash point and pour point properties. The use of a VCI additive with materials having values on the low side of the requirement, could easily result in mixtures having values considerably below the minimum requirement.

Chemical composition of oils supplied for a use specification vary between lots and to a greater extent between suppliers. The VCI concentrate would of necessity be utilized with any number of qualified products. It was, therefore, of paramount importance to determine if the concentrate was compatible with a number of arbitrarily selected qualified producers. The concentrates may have been uniquely compatible with a single source of supply which would present a great supply and logistics problem. MIL-L-2104 being an engine lubricating oil and having a large number of qualified products was selected for this evaluation.

The results of this work have reasonably demonstrated the feasibility of using VCI concentrates in operational lubricants to obtain vapor phase protection comparable to that of the current MIL-L-46002 VCI oil.

Concentrates are available which will meet the desired protection requirements and further work in this area would probably provide concentrates that will more completely satisfy the desired compatibility characteristics and selected physical properties.

On the basis of the data contained in this report, it is recommended that further work be conducted to:

1. Determine the effects of oxidized oils, or oils which have been in storage for a considerable period of time, on the protection, compatibility, and physical characteristics of the oil-concentrate mixtures.

2. Determine the causative effects of the incompatibilities which exist between MIL-L-2104 Grade 30 oil and the VCI concentrates during long term storage.

3. Determine if an inhibitor in a solvent-base concentrate can be effectively utilized in an oil base concentrate.

4. Initiate engine storage tests on the effective VCI concentrates to ascertain their value in actual service.

5. Determine the long term storage characteristics of unused, undiluted VCI concentrates.

6. Determine the most desirable dilution ratio to provide an optimum protection level for use with engine, hydraulic, or general purpose lubricants.

7. Prepare a list of test methods and tentative requirements to define the product in anticipation of a Specification.

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